
Validation of Crown Fuel Amount and Configuration Measured by Multispectral Fusion of Remote Sensors

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Background and Objectives

Current efforts to create continuous fuel and predicted fire behavior layers for the Sierra Nevada bioregion have created a need for consistent bioregional modeling and improved modeling of fuels. At the present time, the different subregions of the Sierra Nevada are mapped during different years and with different methodologies, contributing to inconsistent fuel mapping and fire behavior analysis. Further, there is uncertainty about the accuracy of predictions of crown fuels, namely crown bulk density and height to crown base. Predictions are currently based on indirect measurements from Landsat TM derived maps and associated ground data.

This project was a combined product of both NASA and Joint Fire Science Program (JFSP) funded efforts. The JFSP portion included installation and analysis of a large number of systematically placed field plots. Cooperators at the University of Michigan and Maryland utilized this data and funding from NASA and University sources to analyze the utility of lidar and radar in mapping crown fuels.

We focused on lidar and radar for the Sierra Nevada based upon a workshop for landscape monitoring conducted in the late 1990's. Lidar and radar are both sensors that are able to derive measures from below the top canopy layer. This is important for crown fuel characterization and fire modeling, since the vertical distribution of crown fuels directly influences both the likelihood of crown fire initiation and spread. Lidar has been applied to other regions of the country to map crown fuels but this is the only project that has utilized large footprint, full-waveform lidar. This form of lidar replicates what would be obtained by a satellite based LVIS lidar system that has been deferred by NASA for the current time.

This project is relevant to the primary purposes of the Joint Fire Science Program (JFSP) of: fuels inventory and mapping, and development of protocols for monitoring and evaluation.

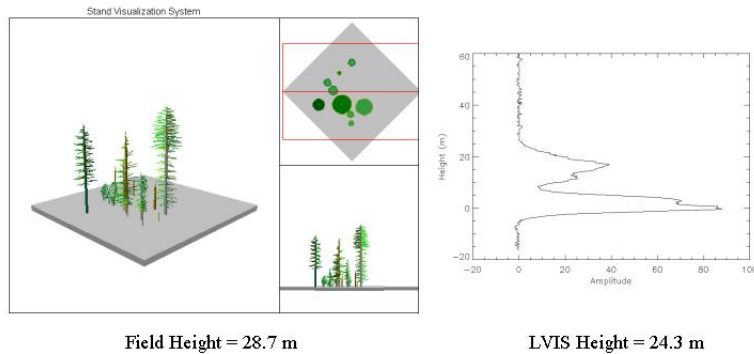
Summary of Findings

Canopy Height and Canopy Cover from lidar

- Results to date show that full waveform lidar can map canopy heights well in the Sierra Nevada ($R^2=0.75$, SE 8.2 m), with increasing accuracy away from plot edges ($R^2=0.93$, SE 4.8 m). Canopy cover was estimated within 8% of measured values ($R^2=0.81$). Biomass was also estimated successfully, with a RMSD of 251 Mg/ha ($R^2=0.83$). Contrary to expectations, slope is not a significant source of error. The relationships between LVIS canopy height and field measured height are similar on high (above the median slope value of ~11%) and low slope areas. Slope was calculated from USGS 30 m DEMs.

Sierra mixed conifer

Plot 84



Ponderosa pine/Sierra mixed conifer

Plot 58

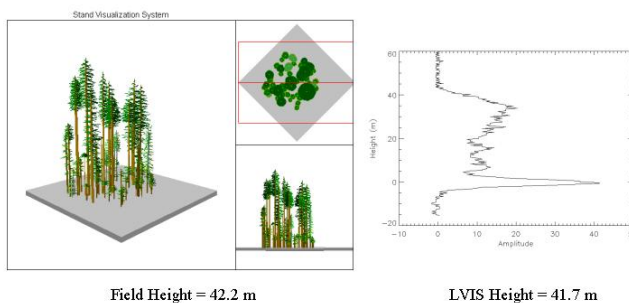


Figure 1. Visualization of stand structure from two plots and associated lidar vertical profile (LVIS) utilized to generate stand height. Field heights and LVIS heights are compared.

- Analysis of canopy cover derived from LIDAR (canopy energy/total energy) and moosehorn canopy cover observations shows reasonable agreement.

LVIS tends to underestimate canopy cover due to very strong ground returns. Improved algorithms will likely correct this problem. No attempt was made here to correct for the occlusion of lower canopy elements by upper ones. Attempts to do this have not yet been successful because coniferous forests violate major assumptions about leaf distributions and contiguity of canopy elements.

Canopy cover validation

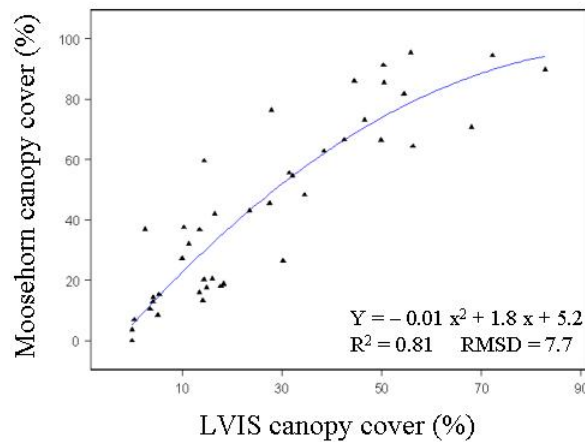


Figure 2. Relationship between field measurements of percent canopy cover (using a moosehorn apparatus) and canopy cover estimated from lidar (LVIS canopy cover).

Canopy Bulk Density and Canopy Base Height from Lidar

- In this study, using multiple linear regression techniques we explored how successfully combinations for various lidar metrics predict CBD and CBH for a study area in the Sierra National Forest. Our results indicate that lidar metrics are significant predictors of CBD ($r^2 = 0.71$) and CBH ($r^2 = 0.59$).

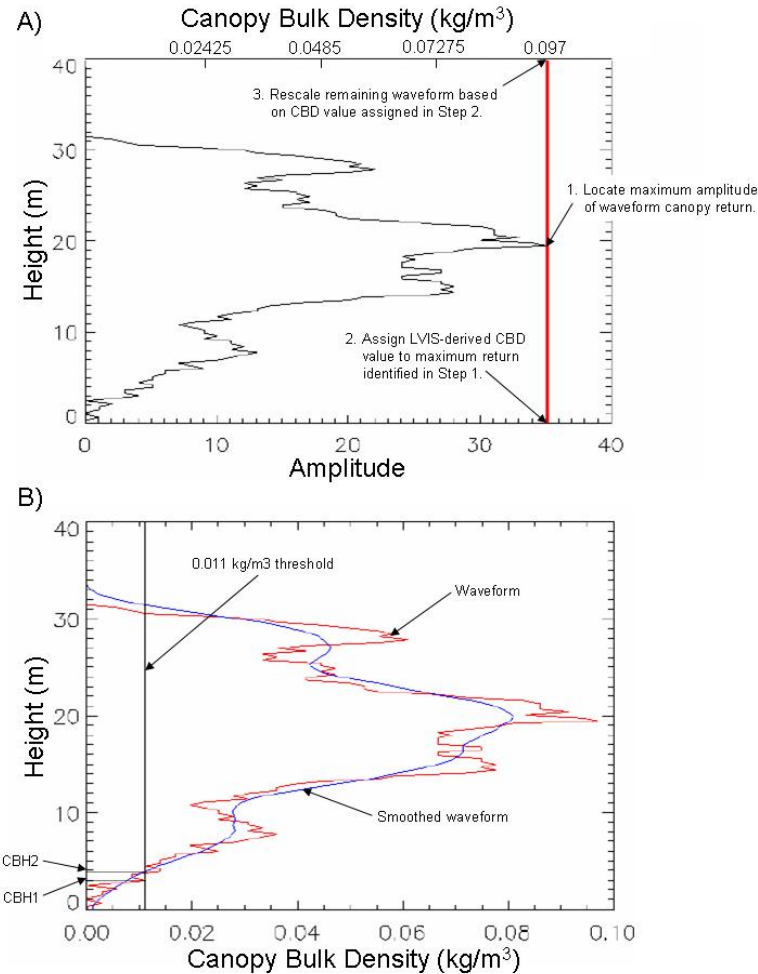


Figure 3. Schematic showing how CBH was derived from lidar-derived CBD profile. The maximum return in the canopy return was found and then assigned the LVIS-derived CBD value (A). Then, this value was used to rescale the remaining canopy return, thereby converting the waveform into a CBD profile. We then applied the same field-based threshold (0.011 kg m^{-3}) in order to derive CBH (B).

Lidar and Implications for Fire Behavior Modeling

- Fire behavior researchers, such as Dr. Finney, have commented that lidar presents one of the most promising advances in crown fuel mapping that would improve fire behavior model inputs.
- Comparisons of FARSITE modeling with standard data that is available to land managers in California, based on extrapolation of average stand conditions from inventory data applied to Landsat Tm data, and with lidar showed differences in fire spread and fire type. We surmise that this is due in part to the ability of lidar to display the full range (both low and high) and spatial variability crown fuels, whereas traditionally available data is limited by stand averages.

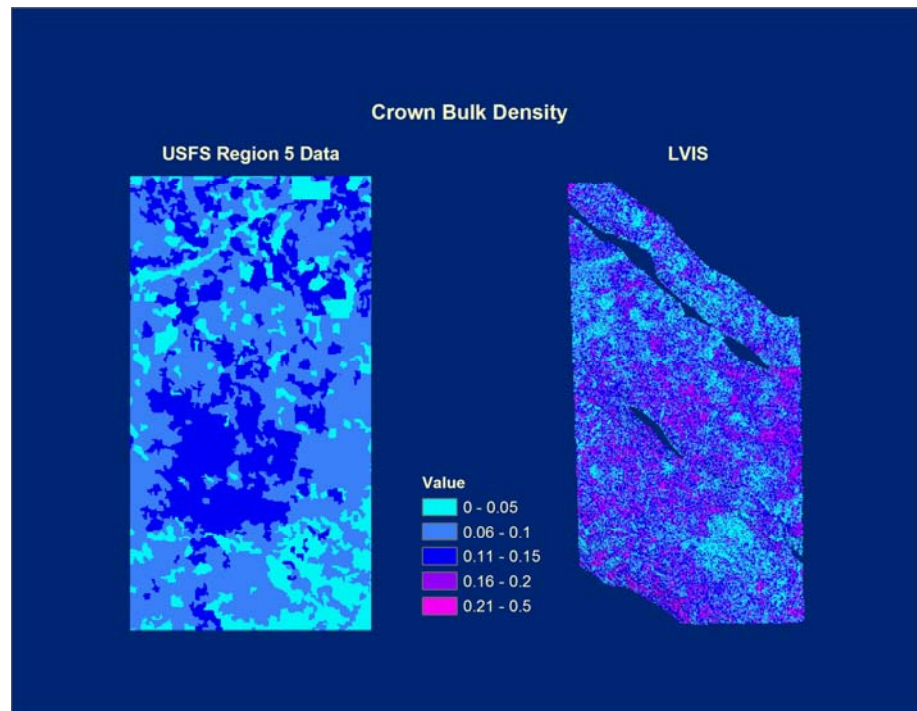


Figure 4. Maps of canopy bulk density for a portion of the southern Sierra study site. The USFS Region 5 data represents what is available in California to managers and is based upon plot averages extrapolated to polygons of vegetation type and structure. The LVIS map was generated from regressions of field data from this study applied to large footprint, full waveform lidar data.

- Our analysis of lidar data demonstrated that it successfully characterized all canopy fuel characteristics across a variety of forest conditions and types, including variable forest structure and steep topography. Previous lidar research related to forest structure and fuels have focused on sites with more uniform forest structure and composition and/or simpler topography.
- This study focused on use of full-waveform, large footprint lidar. Most other applications for crown fuels to date have been with small footprint, partial return lidar. The difference may be significant for canopy fuel modeling and have important implications for fuel modeling and fire behavior applications that need to be further explored.
- This study demonstrated that the canopy profile from full waveform lidar is congruent with that generated with the Reinhardt and Scott approach to analysis of crown fuels from plot data. Large footprint lidar covers larger areas than small footprint, partial return lidar data and therefore may be more useful across larger landscapes or areas. The type of lidar collected here was designed to replicate that which would have been collected by satellite from LVIS. This sensor implementation was indefinitely delayed by NASA.
- Future implications for this work in broader continental or global mapping of crown fuels would be great if NASA resumed the LVIS or similar mission.

- Managers are very interested in being able to access this type of data for their use.

Radar

- The radar portion of this study was more limited than the lidar portion. Original objectives were to evaluate all canopy fuel characteristics but canopy height was the only characteristic evaluated by the University of Michigan group. This was due in part to greater difficulty encountered in utilizing the radar data in the complex terrain of the Sierra Nevada than anticipated.
- Methods developed to generate canopy cover maps using radar satellite data were expanded to mapping canopy cover across the conterminous United States.

Fusion of Lidar, Radar and Landsat Tm Data for Crown Fuel Mapping

- Delay of the radar portion resulted in no analysis of the potential of fusion of lidar, radar and Landsat Tm data for mapping crown fuels. The potential for utilizing radar and Landsat Tm data to extend the more detailed data from lidar needs to be further explored. Some related work by the University of Maryland and NASA has been conducted on this but not specifically on canopy fuel characteristics.

Field Locations

Two study sites were established in the Sierra Nevada mountain range of California, representing the northern and southern areas of the bioregion. The northern location is on the Plumas National Forest, encompassed by the Herger-Feinstein/Quincy Library Group EIS area. The southern location is on the Sierra National Forest, and includes the King's River Administrative Study Area and the Teakettle Experimental Forest.

The northern project site was located approximately 40 km west of Quincy, CA (T 24N, R 9E, Section 14) at elevations of 1200 to 1850 m. The study area covered \approx 20,000 hectares of coniferous forest and spanned in latitude from 39° 47' 30" to 39° 57' 30" and in longitude from 120° 57' 30" to 121° 12' 30". The northern Sierra Nevada has a warm, dry summer and a cool, wet winter climate. Vegetation types include mixed conifer forests of white fir (*Abies concolor*), ponderosa pine (*Pinus ponderosa*), incense cedar (*Calocedrus decurrens*), sugar pine (*Pinus lambertiana*), and Douglas fir (*Pseudotsuga menziesii*), with ponderosa pine dominate in relatively dry locations and white fir dominate in moister locations. Upper elevation plots consisted of red fir (*Abies magnifica*) and Jeffrey pine (*Pinus jeffreyi*) dominated vegetation types (Sawyer and Keeler-Wolf, 1995).

The southern project study area was located approximately 80 km east of Fresno, CA (T 13S, R 20E) at elevations of 1500 to 2600 m. The project area covered \approx 40,000 hectares of the Sierra National Forest and spanned in latitude from 36° 55' to 37° 20' and in longitude from 119° 00' to 121° 12'. The southern Sierra Nevada has a warm, dry summer and a cool, wet winter climate. Vegetation types include lower elevation mixed

conifer forests of white fir (*Abies concolor*), incense cedar (*Calocedrus decurrens*), sugar pine (*Pinus lambertiana*), and Jeffrey pine (*Pinus jeffreyi*). Upper elevation plots consisted of red fir (*Abies magnifica*), lodgepole pine (*Pinus contorta*), and western white pine (*Pinus monticola*) vegetation types (Sawyer and Keeler-Wolf, 1995).



Figure 5. Map of study locations. The lidar portion of the study included only the southern Sierra Nevada site on the Sierra National Forest. The radar portion included both the southern Sierra site on the Sierra National Forest and the northern site on the Plumas National Forest.

Deliverables

| Proposed | Delivered | Status |
|--------------------------------------|---|-----------------------------------|
| Website | http://www.fs.fed.us/adaptivemanagement/projects/joint_fire/index.shtml | done |
| Design & document field protocol | Documented and reported in progress report and provided to remote sensing cooperators | done 2001 |
| Compile raw and analyzed data | Database with raw data and analyzed data completed and provided to remote sensing cooperators | done 2001 |
| Presentations at scientific symposia | Poster at the 8 th biennial remote sensing applications conference of the US Forest Service | done 2001 |
| | Poster at the Sierra Nevada Science Symposium | done 2002 |
| | Presentation at the International Fire Ecology Congress, Orlando Florida | done 2003 |
| Presentations to fire managers | Presentations to the California Fuels Committee | done 2002, 2003, 2004 |
| | Presentation to the Western Region Park Service Fire Management Meeting | done 2003 |
| | Presentations to the USFS Region 5 Fire Management Officers and Director | done 2002, 2003, 2004 |
| Publications | Peterson, B. 2005. Canopy Fuels Inventory and Mapping Using Large-Footprint Lidar, Dissertation, University of Maryland. | Done 12/05 |
| | Peterson, B., R. Dubayah, P. Hyde, M. Hofton, J.B. Blair and J. Fites-Kaufman (in review, Remote Sensing of Environment). Canopy Fuels Inventory for Fire Modeling in a Montane Forest Environment using Lidar Waveform Data. | In review (6/06) |
| | Peterson, B., R. Dubaya, J. Fites-Kaufman (in preparation). FARSITE Modeling Using Structure Inputs Derived From Lidar (for submission to International J. Wildland Fire) | in preparation, planned fall 2006 |
| | Wayne W. Walker, 2006. Toward Regional- to Continental-Scale Estimates of Vegetation Canopy Height: An Empirical Approach based on Data from the Shuttle Radar Topography Mission. Ph.D. Dissertation at The University of Michigan | done 5/2006 |
| | Josef Kelldorfer, Wayne Walker, An Empirical SRTM-based Approach to Mapping Vegetation Canopy Height for the Conterminous Unites States, Submitted to "Remote Sensing of Environment". | in review (6/2006) |
| | Hyde, P., R. Dubayah, B. Peterson, J.B. Blair, M. Hofton, C. Hunsaker, R. Knox, W. Walker. 2005. Mapping forest structure for wildlife habitat analysis using waveform lidar: Validation of montane ecosystems. <i>Remote Sensing of Environment</i> , vol. 96: 427-436 | done 2005 |